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STUDY OF AIRCRAFT NOISE DURING TAKE-OFF

by

Marc Pianko

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TRANSLATOR'S NOTE:

MOTEUR DILUÉ

&

TAUX DE DILUTION

A literal translation of these expression was made, to wit, DILUTED ENGINE & DILUTION RATE, because it was impossible to determine the exact translation of the term "dilué," despite consulting both a French engineer and a power plant engineer in the area.

TAUX DE MOTORISATION have been translated as POWER RATING & ENGINE POWER (or

&

simply power in some cases), for the same reason.

MOTORISATION

STUDY OF AIRCRAFT NOISE DURING TAKE-OFF*

by

Marc Pianko**

ABSTRACT

The optimum paths providing for minimization of the noise level of an aircraft during take-off are studied first. Determination of those paths emphasizes the aircraft parameter which -- apart from engine noise -- establishes the noise intensity at take-off. The relative effect of each parameter is evaluated. The influence of engine technology, its restrictions and limitations on future progress in the field of take-off noise is then examined. The extent to which the results may be altered by the introduction of the effective PNdB (duration correction) is finally examined.

Optimum Paths

When a given aircraft is on a level-flight pattern (Fig. 1,b) the noise recorded at a measurement point M established on the track has the shape indicated in Fig. 1,b as a function of the angle β formed by the sound vector and the path, the maximum N_m is attained for an angle β_m generally ranging between 130° and 150° . The curve in Fig. 1,b, called linear sound field, depends on several parameters, particularly engine cycle, flight speed, the distance h from the point M to the path, the setting of the engines in the aircraft, and the pitch of the aircraft. The variation of N_m as a

* Adapted from the report submitted to the 33rd AGARD Conference on aircraft-engine noise and sonic boom organized by the "Fluid Dynamics" and "Power and Propulsion" Work Groups, and held in May 1969 at Saint-Louis, France.

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function of distance follows a law of $20 \log 1/d$, corrected for atmospheric absorption. Generally, N_m can be represented in PNdB by $K \log 1/d$. Although it depends on the cycle and size of the engine, K varies in practice between 20 and 30. When jet noise predominates, K is given by $K = 20 + \lambda h/435$, where the atmospheric attenuation λ expressed in PNdB per 1000 m is essentially a function of the nozzle diameter and of the specific thrust in flight at take-off thrust power F_1/D_1 (Fig. 2). In contrast, when compressor noise predominates, K depends on a number of parameters, such as the diameter of the compressor, peripheral velocity, number of blades, but its value is generally in the neighborhood of 27.

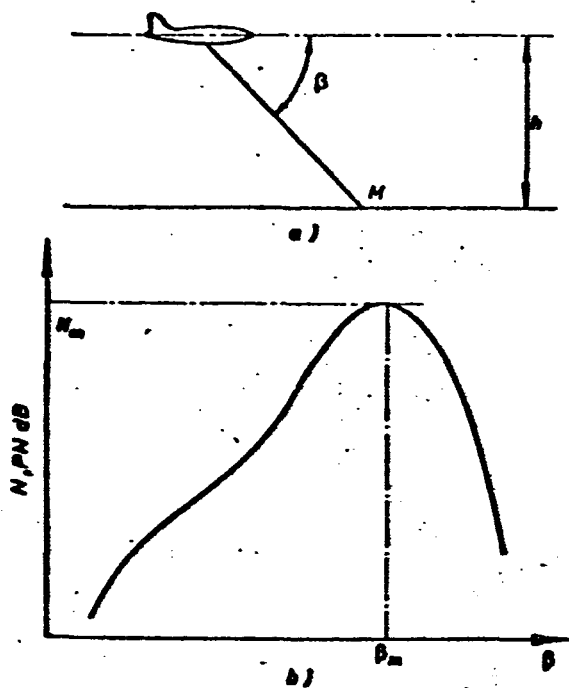


Fig. 1. Sound field of an aircraft in level overflight.

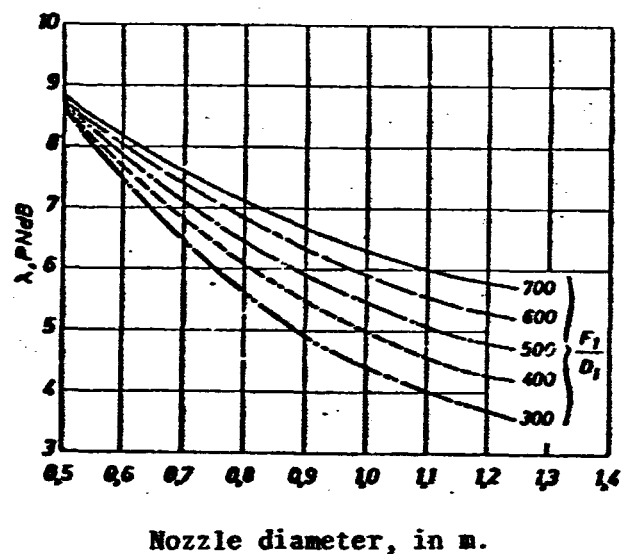


Fig. 2. Atmospheric attenuation per 1000 m λ as a function of nozzle diameter and specific thrust in flight at take-off thrust power F_1/D_1 .

[Translator's note: Commas in tabulated numerals are equivalent to decimal points.]

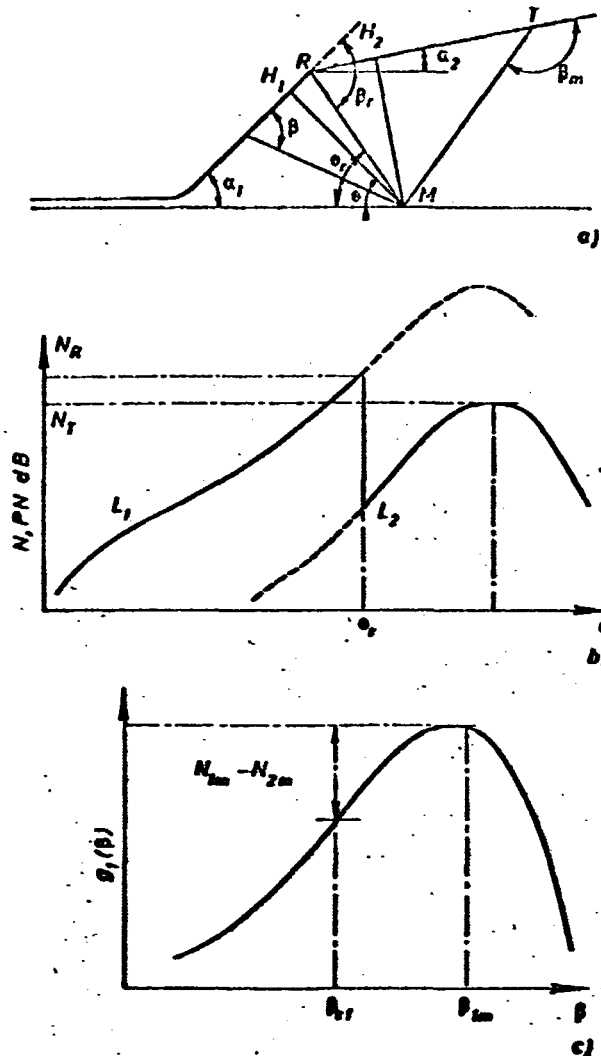


Fig. 3. Investigation of the optimum reduction point.

If instead of being on a level flight path the aircraft is on a take-off path -- which path can be schematically represented by the two angles α_1 and α_2 (Fig. 3,a) -- the noise recorded at M has a different shape as a function of the angle θ formed by the sound vector and the horizontal plane as indicated in Fig. 3,b. The two line segments are distinguished as follows: the first one, L_1 , is the sound field corresponding to the initial path with a maximum N_R attained for the value $\theta = \theta_r$ of the reduction point R , the second one, L_2 , is a portion of the sound field corresponding to flight

conditions after reduction with a maximum N_T derived from the maximum emission angle β_{2m} . The first maximum N_R is lower than the maximum N_{1m} which would have been attained had there been no reduction.

Point of Optimum Reduction.

The take-off path can be optimized so that the noise level at M is minimal. Since the angle α_1 is determined by the take-off thrust power of the engines, and since the angle α_1 has a minimum value imposed by safety regulations, the only parameter one can work with is the position of the reduction point R . Since the noise at M is determined by the noise-level maximum, the optimum reduction point is the one involving the equality of N_R and of N_T .

On line L_1 noise N_1 can be represented by:

$$N_1 = N_{1m} - g_1(\beta)$$

where N_{1m} is the noise at the maximum emission angle β_{1m} at the reference distance h_1 ($h_1 = MH_1$) and $g_1(\beta)$ a function representing the sound field on the first segment of the path whose origin (O) will be established for $N_1 = N_{1m}$ (Fig. 3,c). The peak N_R , obtained for $\theta = \theta_r$, has the value:

$$N_R = N_{1m} - g_1(\beta_r)$$

where

$$\beta_r = \theta_r + \alpha_1$$

Likewise, on line L_2 the noise N_2 can be represented by

$$N_2 = N_{2m} - K_2 \log h_2/h_1 - g_2(\beta)$$

where $h_2 = MH_2$; K_2 differs from K_1 by virtue of the reduction in engine thrust power, and $g_2(\beta)$ is a function representing the sound field on the second segment of the path. The peak N_T , derived from β_{2m} , i.e., from a value of β such that $g_2(\beta) = 0$, has the value of:

$$N_T = N_{2m} - K_2 \log h_2/h_1$$

The equality of N_R and of N_T thus yields:

$$N_{1m} - N_{2m} = -K_2 \log h_2/h_1 + g_1(\beta_r)$$

Following certain elementary transformations, this equation is written:

$$N_{1m} - N_{2m} = K_2 \log \frac{\sin(\theta_r + \alpha_1)}{\sin(\theta_r + \alpha_2)} + g_1(\theta_r + \alpha_1)$$

Three iterations generally suffice to solve this equation and obtain the desired value of β_r .

Noise Level at the Measurement Point.

When the take-off path is optimized the noise level at the measurement point M is equal to $N_{1m} - g_1(\beta_r)$, whereas without the reduction its value would be N_{1m} ; the gain obtained by reduction is therefore equal to $g_1(\beta_r)$ and increases when the curve $g_1(\beta)$ is higher.

It should be noted that the sound field $g_1(\beta)$ differs from the sound field obtained during level overflight by reason of the difference in pitch of the aircraft while climbing and while on level flight. If the noise level during level flight is represented by $N_h(\beta) = N_m - g(\beta)$, the noise level while climbing at the same distance and at the same speed is given by:

$$N_v(\beta) = N_m - K_1 \log \sin(\beta + \Delta\xi)/\sin \beta - g(\beta + \Delta\xi).$$

$\Delta\xi$ being the difference in pitch. The maximum of N_h is N_m , but that of N_v , in the neighborhood of $N_m - \log \sin \beta_m/\sin(\beta_m - \Delta\xi)$, is greater than N_m , because β_m is of the order of 130° to 150° .

Like $N_{2m} - K_2 \log h_2/h_1$, the noise level is thus determined by the noise of the engines themselves in order to maintain the established angle α_2 and by the altitude h_2 attained.

It is therefore necessary to attain the highest altitude possible during the first phase of climb (prior to reduction). Altitude depends almost

entirely on the design and aerodynamic performances of the aircraft; the parameters determining the length of the runway (power rating, wing loading, drag and C_{zmax}), and those determining the initial angle of climb (power rating, lift/drag ratio¹) are therefore of prime importance for the noise level at M . Two other parameters, the rate of climb selected and flap configuration, are also involved. Although the lower the speed the greater the angle of climb α_1 , the majority of the aircraft climb, in practice, at an economical speed 10, 15, and even 20 knots greater than the minimum speed imposed by safety standards. Flap configuration is not chosen to make h_2 maximal, but on the basis of other considerations; in each specific case, in fact, the optimum configuration of the flaps should be studied to minimize the noise level at the selected measurement point. Insofar as the engine is concerned, it is involved only as a result of the variation in thrust as a function of speed.

Since engine-noise level at reduced thrust power is the determining factor, all efforts made to reduce engine noise at full thrust power are useless if they have no effect on engine noise at reduced thrust power (after reduction), and they can even be detrimental if they degrade take-off and climb performances. This conclusion applies only to noise on the take-off track of an aircraft using reduction; what matters for the sideways spread of noise is the noise at full thrust power. Involved here is the key problem of mufflers which, by creating a loss of thrust at take-off, degrade the performances during take-off and climbing, and which generally have a diminished acoustical effectiveness at low thrust power; the gain achieved with mufflers on aircraft is always limited, except for the gain obtained at the fixed point.

¹ L/D ratio will be used for lift/drag ratio hereinafter. [Translator's note.]

Possible Interest in More Complicated Take-off Paths.

One may ask whether the results obtained by a simple reduction are not capable of being improved by the adoption of more complicated take-off paths, i.e., a law of progressive reduction, which the pilot probably could not apply.

In the equation that determines β_r

$$N_{1m} - N_{2m} =$$

$$K_2 \log \sin \beta_r / \sin (\beta_r - \alpha_1 + \alpha_2) + g_1 (\beta_r)$$

the first term of the second member is a correction term intended to take into account the loss of altitude resulting from reduction. The most sophisticated path could thus only lead to a gain of that quantity that is generally small opposite $N_{1m} - N_{2m}$. It may be said that $N_{1m} - N_{2m}$ is the maximum potential gain of all possible paths, and that the actual gain is reduced by a quantity that depends on the path. This conclusion is not valid in the case where, when $N_{1m} - N_{2m}$ is very small, the study of an optimized reduction leads to $\beta_r > 90^\circ$; then the actual gain is greater than $N_{1m} - N_{2m}$, since $h_2 > h_1$.

Nevertheless, in order to determine the possible advisability of more complicated paths, the possibilities of a double reduction were studied. In the case of the Caravelle, a gain supplement of 0.6 PNdB is obtained. The study of climb paths more complicated than a simple reduction may, however, be of substantially greater interest when the sound field is very flat, and when a simple reduction leads to too much loss of altitude.

Noise Level on the Track.

It is essential to know not only the noise level at M when reduction is optimized for a point, but also the manner in which noise develops further along the track.

On the track (Fig. 4,a) there is a point C such that CR forms with the first segment of the path the angle β_{1m} of maximum emission; its position is

defined by:

$$\frac{MC}{MH_1} = \frac{[\cos \theta_r + \sin \theta_r \cotg (\gamma_{1m} + \alpha_1)]}{\sin \beta_r}$$

where $\gamma_{1m} = \pi - \beta_{1m}$ et $\beta_r = \theta_r + \alpha_1$.

For all points situated ahead of C , reduction has no influence on the sound level determined by the angle of maximum emission encountered prior to reduction. The curve C_M (Fig. 4,b), representing the sound level as a function

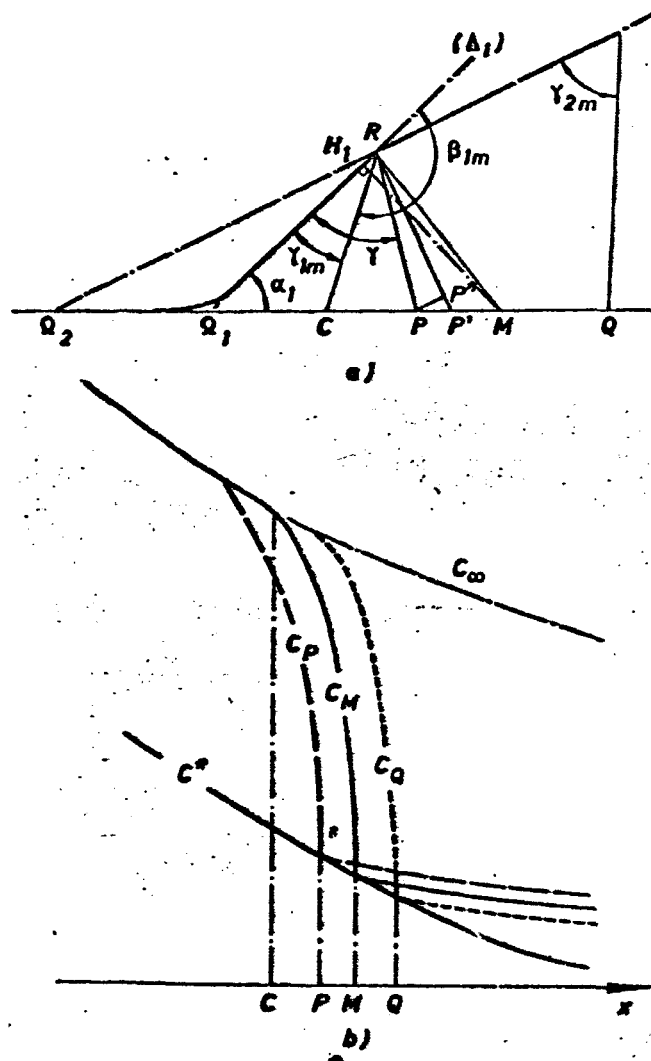


Fig. 4. Noise level on the track.

of the distance to the point of brake release, agrees with the curve C_∞ representing the development of noise for a take-off path without reduction (on C_∞ the level varies as $K_1 \log 1/\text{distance to point } \Omega_1$).

For the points P situated between C and M , the noise level is given by the first peak, i.e., the sound level emitted from R , since reduction takes place too late. When one passes from point P to a more distant point P' , the decrease in the noise level from P to P' is due on the one hand, to the increase of the angle γ (passage from P to P''), and on the other hand to the increase of the distance to the straight line Δ_1 (passage from P'' to P').

$$\Delta N = \frac{\delta N}{\delta \alpha} \Delta \gamma + \frac{\delta N}{\delta d} \Delta d$$

At C , $\gamma = \gamma_{1m}$ and $\frac{\delta N}{\delta \gamma}(\gamma_{1m}) = 0$, so that the variation in sound level is due only to the variation of the distance: the curve C_m is therefore tangent to C_∞ . Beyond C , the slope of C_M , due specifically to the variation of γ , is quite steep.

For the points Q situated after the point M , reduction takes place too soon and the noise level is determined by the angle of maximum emission γ_{2m} (second peak). On this portion of C_M , the level varies as $K_2 \log 1/\Omega_2 Q$, i.e., less than on C_∞ . The slope of C_M thus suffers a discontinuity at M .

Fig. 4,b shows the plotting of the different curves CM whose network, for a given aircraft, is a function of external temperature, humidity in the air, and above all the mass of the aircraft at take-off; curve C^* represents the place of minimized sound levels.

As one can also see in Fig. 4,b, the difference in noise produced by three neighboring reductions is small throughout except, precisely, at point M where the noise is sought to be minimized. If reduction takes place too soon at P' the noise variation at M is $\Delta N' = N' - N = \frac{K_2}{2.3} \frac{\Delta h_2}{h_2}$; if it takes place too late at P'' , it is

$$\Delta N'' = N'' - N = \frac{\delta N}{\delta \theta} \Delta \theta = \frac{dg_1}{d\beta} \Delta \theta$$

Actually, the pilot does not reduce according to the angle from which he sees the measurement point, but at an imposed altitude z . In this case,

$$\Delta N' = \frac{K_2}{2.3} \frac{\alpha_1 - \alpha_2 \sin(\beta_r - \alpha_1)}{\alpha_1 \sin(\beta_r - \alpha_1 + \alpha_2)} \frac{\Delta z}{z}$$

$$\Delta N'' = \frac{dg_1(\beta_r)}{d\beta} \frac{\sin(\beta_r - \alpha_1) \sin \beta_r}{\alpha_1} \frac{\Delta z}{z}$$

For the Caravelle II, $\Delta N' = 7.45 \Delta z/z$ and $\Delta N'' = 26.7 \Delta z/z$. The recording (Fig. 5) made during a recent test with the Caravelle shows that a slight delay in reduction (error of 6 m in altitude) increases the level at M by 2 dB, while too premature a reduction (error of 55 m in altitude) increases the sound level by only 1 dB.

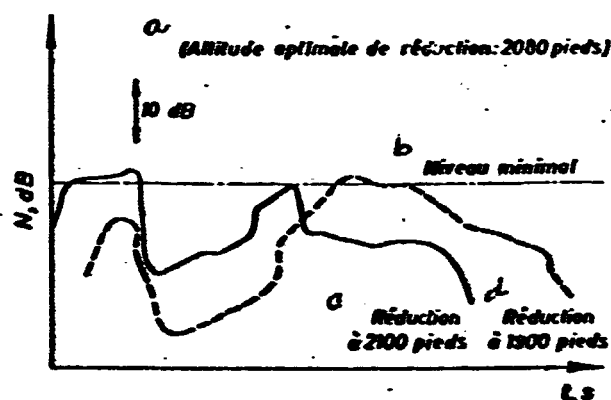


Fig. 5. Recording of take-off noise of the Caravelle III.

- Key:
- a. Optimum reduction altitude: 2080 ft.
 - b. Minimum level.
 - c. Reduction at 2100 ft.
 - d. Reduction at 1900 ft.

This phenomenon is one of the reasons for the great dispersion of the measurements of aircraft take-off noise, but it is not the only one. The reduction point is actually determined by the angle from which the aircraft is viewed; during tests, the optimum angle can be altered by a gust of wind, or by any other nonstationary movement which has little effect on the path or pitch of the aircraft at the instant of measurement, but which has a substantial influence on the angle from which it is viewed. Any measurement made at the time of take-off with reduction must therefore be controlled at one or two measuring points situated immediately past point M (of the order of 100 and 300 m downstream).

Protection of an Inhabited Area.

Protection of an inhabited area is a different overall problem than the one dealt with above, which is a local problem associated with a single point. Its solution depends not only on the geometrical configuration of the area involved, but also on the density of population and the very definition of minimum noise over an inhabited area. Needless to say that knowledge of the entire network of C_M curves of each aircraft will make it possible to handle the reduction possibilities that much better and to adapt them to inhabited areas surrounding each airport. While the current standard anti-noise procedure consists most frequently in reducing at a given altitude, better protection of the population might be ensured by selecting a procedure as a function of the area to be protected, of meteorological conditions, and of the aircraft mass during take-off.

Reduction Gain

As seen above, the potential reduction gain is equal to $N_{1m} - N_{2m}$. If the maximum engine noise at take-off thrust power N_{1m} depends only on the engine,

the maximum noise of the engine at reduced power N_{2m} depends not only on the engine but also on the residual angle of climb α_2 , on the L/D ratio of the aircraft, and on engine power. Strictly speaking, the speed of the aircraft is also involved, but taking a Mach number of climb of 0.23 there is a negligible error of less than 0.1 PNdB.

Jet Noise

If one accepts an error of ± 0.5 PNdB resulting from the adoption of a mean law of variation in specific fuel consumption as a function of specific thrust (Fig. 6), the application of the SNECMA method (technical note Ylla No. 169) enables one to represent the variation in the jet noise of engines as a function of specific thrust (Fig. 7).

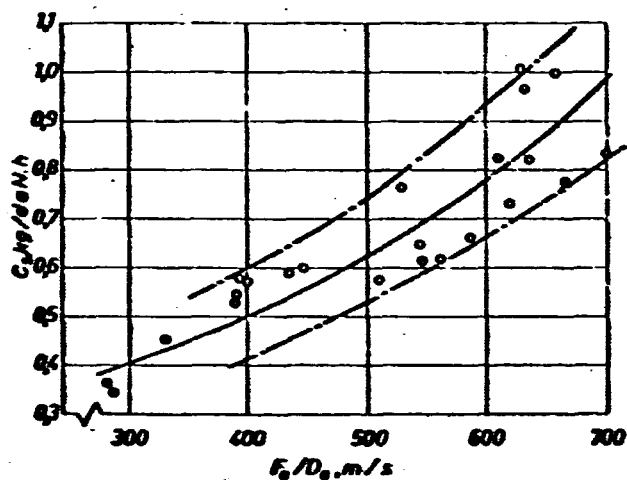


Fig. 6. Relation between specific fuel consumption C and specific thrust at a fixed point on the ground F_0/D_0 .

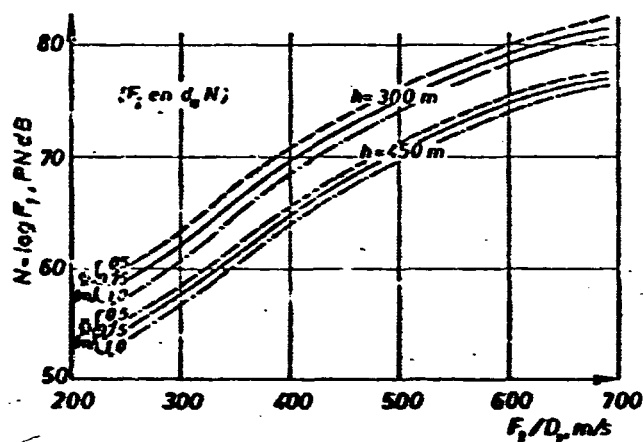


Fig. 7. Jet noise in flight as a function of specific thrust, of the distance h , and of nozzle diameter ϕ .

On the initial path (angle α_1) the engine, generally characterized by its thrust at the fixed point on the ground F_0 , is working at maximum power. The corresponding thrust F_1 and specific thrust F_1/D_1 can be calculated as a

function of the Mach number of climb with the aid of Figs. 8 and 9.

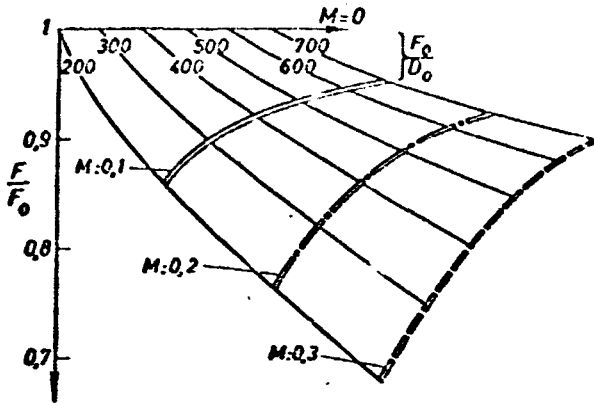


Fig. 8. Thrust in flight F as a function of Mach number M and specific thrust F_0/D_0 .

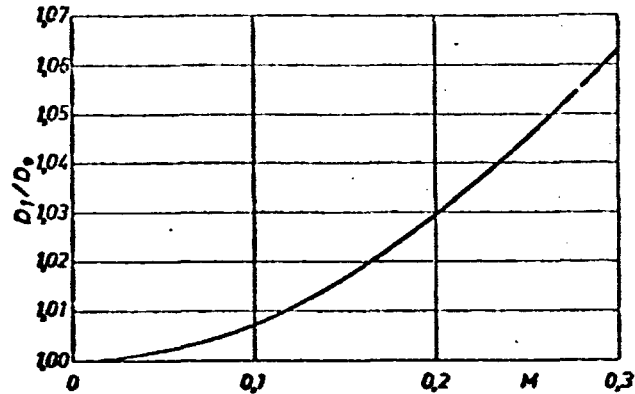


Fig. 9. Flow in flight at take-off thrust power D_1 as a function of Mach number M .

Following reduction (angle α_2), the thrust F_2 is given by $F_2/mg = \alpha_2 + 1/\psi$, ψ being the L/D ratio and mg the weight of the aircraft. Insofar as specific thrust F_2/D_2 is concerned, it can be calculated with the aid of a mean law (Fig. 10,b) established after observing that for different engines $\frac{F/F_1}{D/D_1}$ is virtually a linear function ($\pm 3\%$) of F/F_1 (Fig. 10a).

Compressor Noise.

According to the SAE AIR 973 method, as amended by SNECMA, which has introduced a convection factor for ducted-fan engines (technical note Ylla No. 169), the maximum linear level at 300 m is given by:

$$M - 10 \log F = -15 + 46 \log U_e - 10 \log D/s - 10 \log F/D$$

where F is measured in daN , U_e is the peripheral velocity at the tip of the blade of the first compressor stage expressed in m/s , and s the intake area of the jet engine in m^2 .

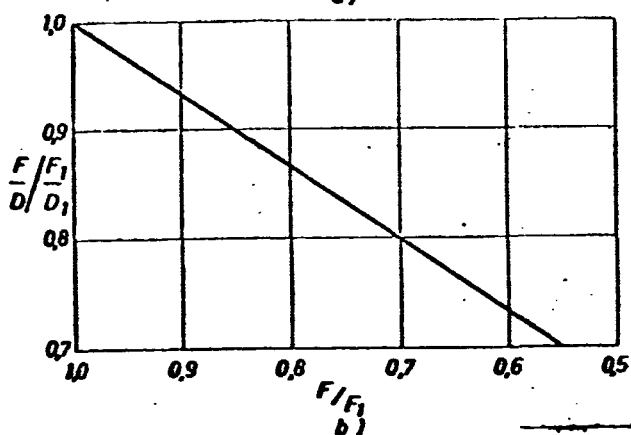
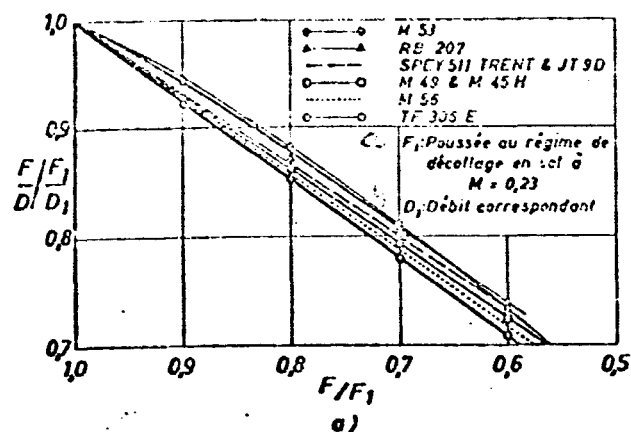


Fig. 10. Variation of specific thrust as a function of thrust.

Key: a. F_1 : Take-off thrust power in flight at $M = 0.23$
b. D_1 : Corresponding output

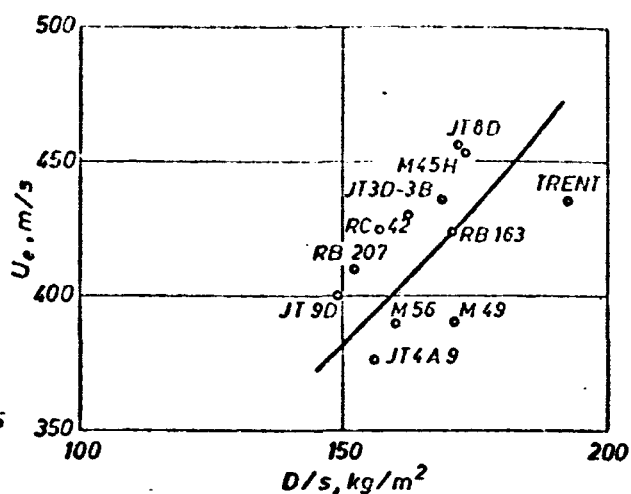


Fig. 11. Relationship between peripheral velocity U_e and specific output D/s

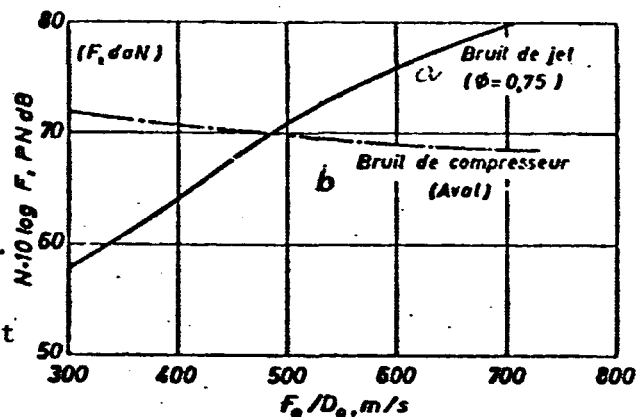


Fig. 12. Noise of a reactor in flight at take-off thrust power

Key: a. Jet noise.
b. Compressor noise (downstream).

$U_e = 425 \text{ m/s}$ and $D/s = 170 \text{ kg/m}^2$ represent a good average (Fig. 11).

Under these conditions, the convection factor for the noise downstream of the compressor is $+3 \text{ PNdB}$. $N - 10 \log F$ can therefore be represented as a function of F_0/D_0 (Fig. 12); it will be seen that for F_0/D_0 lower than 490 m/s , the downstream compressor noise is greater than the jet noise.

By reason of the complexity of the compressor noise, which depends on a multitude of parameters (peripheral velocity, number of blades, number of

stages, rotor-stator deviation, presence of the intake impeller), this result must be treated with considerable care; not too much reliance should be placed on absolute values, but rather tendencies and orders of magnitude should be considered.

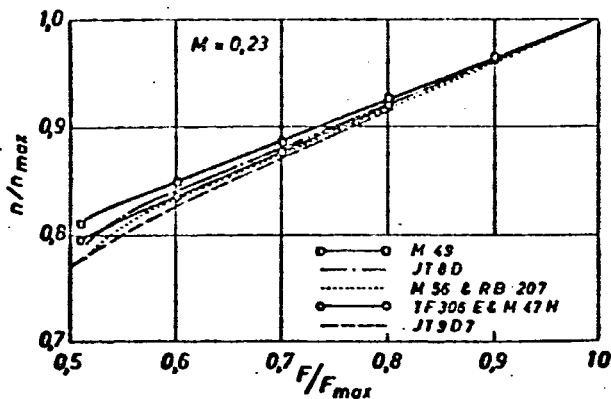


Fig. 13. Variation of thrust as a function of rotation velocity n .

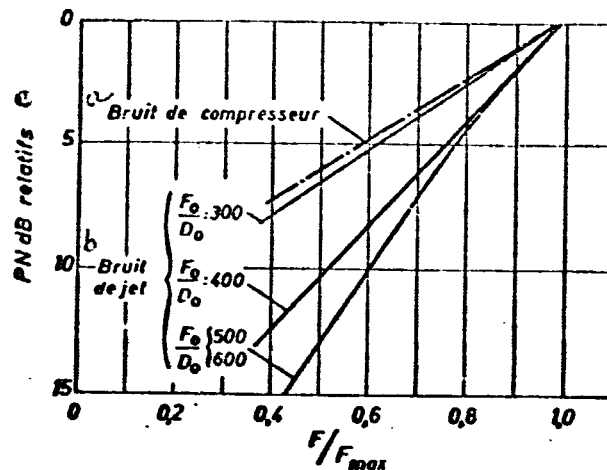


Fig. 14. Noise of jet engine in flight as a function of thrust.

Key: a. Compressor noise.
b. Jet noise.
c. Relative PNdB.

As shown in Fig. 13, one can adopt a mean law of variation of thrust as a function of engine speed so that the variation in the noise level of the compressor can be represented as a function of thrust (Fig. 14); it will be seen that for a very diluted [?] engine ($F_0/D_0 = 300$, or a dilution rate of the order of 4 to 5), the variation in jet noise is very close to that of the compressor noise.

Results.

Fig. 15, which gives the potential reduction gain for three different L/D ratios as a function of the power rating P_0/mg , enables one to verify the

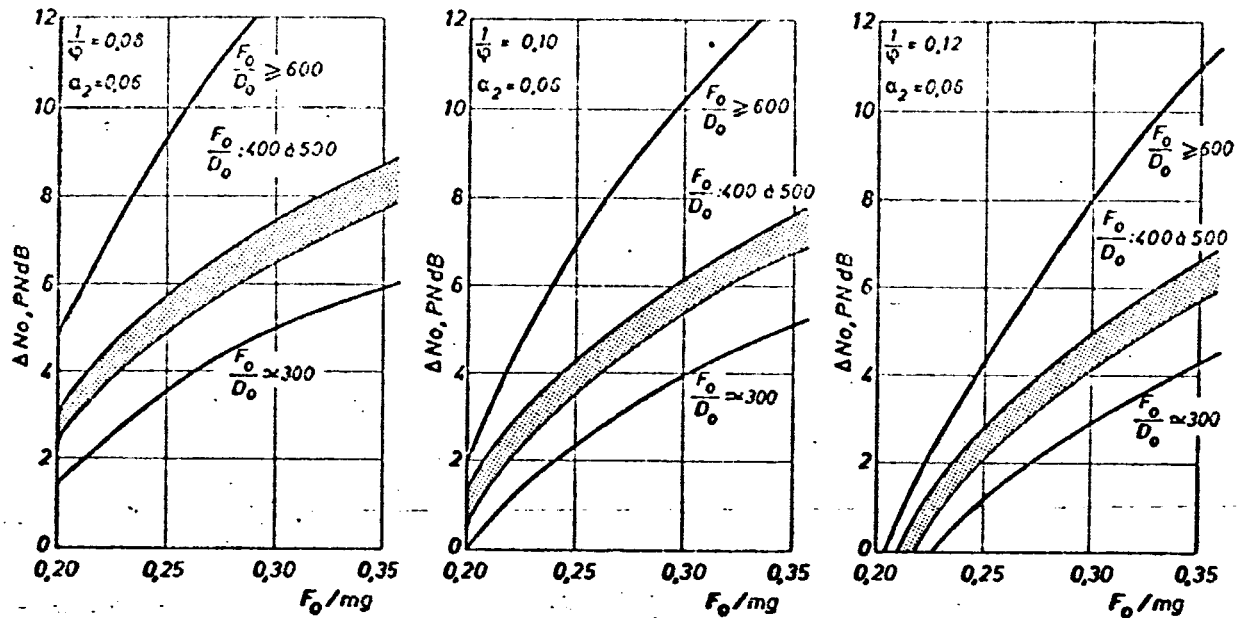


Fig. 15. Potential reduction gain ΔN_0 as a function of the engine power F_0/mg and of the L/D ratio ψ .

following:

1. For aircraft equipped with pure jets ($F_0/D_0 \geq 600$), the gain may be very substantial, especially at high power ratings due to the fact that the compressor noise is negligible, and that the jet engine loses very little of its thrust in flight.

2. For aircraft equipped with very diluted engines ($F_0/D_0 = 300$), or a dilution rate of the order of 4 to 5), the potential gain is much smaller, particularly by reason of the great loss of thrust in flight in relation to static thrust. The gain would remain virtually the same if compressor noise could be suppressed entirely.

3. For aircraft equipped with moderately diluted engines ($F_0/D_0 = 400-500$, or a dilution rate of the order of 1 to 2), the gain is relatively small, closer to that of very diluted engines than to that of pure jets. Compressor noise is substantially involved and flattens the curve giving the

overall noise level as a function of thrust. Gain would be much greater if the compressor noise could be suppressed.

The influence of the L/D ratio and of the residual angle of climb α_2 are shown in Fig. 16.

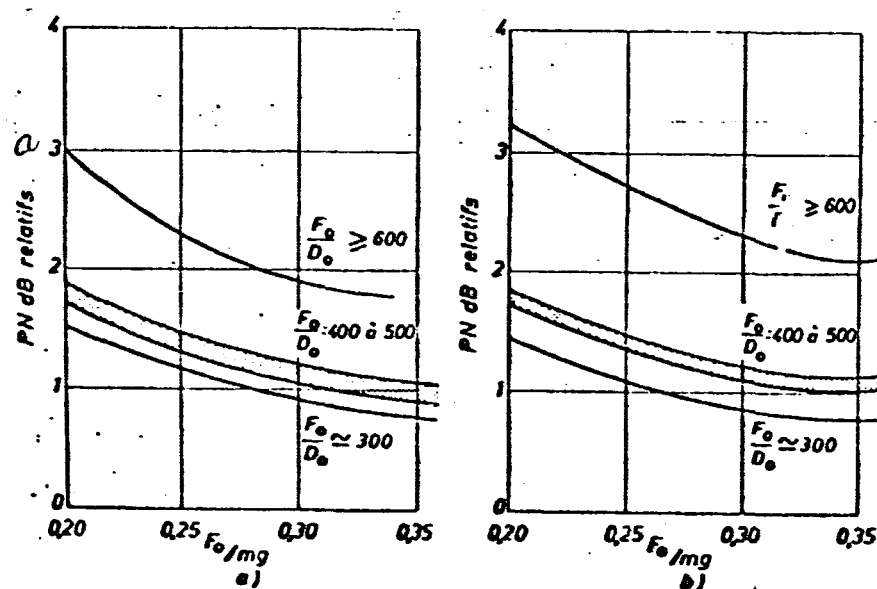
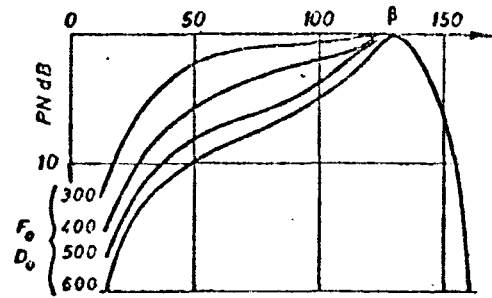


Fig. 16. Variation of reduction gain when the L/D ratio increases by two points (a), and when the angle α_2 passes from 0.04 to 0.06 (b).

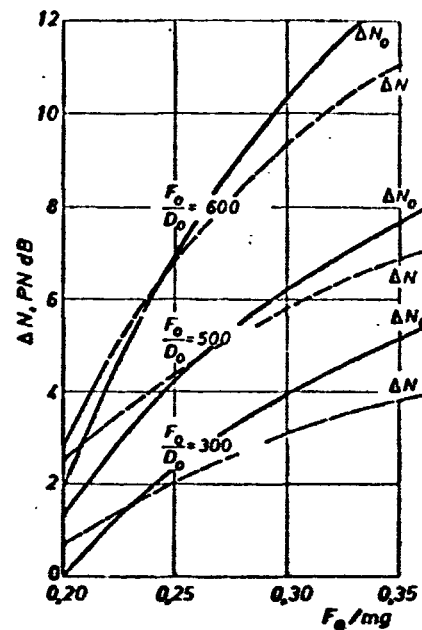
Key: a. Relative PNdB.

The influence of power rating, L/D ratio, and angle of climb is much less with very diluted jet engines than with pure jets: For future aircraft equipped with very diluted jet engines, the difference between aircrafts will thus be greatly attenuated.

The gain values given above are potential gains, i.e., excluding the sound field. If for each value of F_0/D_0 one takes a different sound field (Fig. 17,a), the differences between the potential gain ΔN_0 and the actual gain ΔN are variable (Fig. 17,b); their relative value is particularly important for a



a)



b)

Fig. 17. Influence of the sound field on reduction gain.

very flat sound field. As already indicated, the actual gain may be greater than the potential gain when reduction is obtained after flight over the observer ($\beta_p > 90^\circ$).

Aircraft Take-off Noise

Having studied the influence of power rating P_0/mg and of specific thrust F_0/D_0 on reduction gain, we will now examine their influence on take-off noise without reduction. To this end, two types of aircraft are studied, a twin-engined

and a four-engined aircraft; Table I summarizes the characteristics involved in the calculation of the take-off distance.

TABLE I. Characteristics involved in the calculation of take-off distance for the two types of aircraft considered.

	Type of Aircraft	
	Twin-engined	Four-engined
M/S	470	530
C_{zmax}	1.9	2.2
C_x	0.065	0.10
C_z	0.4	0.8
F_o/D_o	600	300

Fig. 18, which gives the relative development of the sound level without reduction at 6,500 m from the point of brake release as a function of power rating, shows the very substantial influence of the power rating which is the basic parameter in the determination of take-off noise: a 10% increase in power rating gives a gain of 2.8 PNdB for a twin-engined aircraft with $F_o/mg = 0.265$, and for a four-engined aircraft with $F_o/mg = 0.23$ (respectively 3.6 and 4 PNdB if reduction gain is taken into account).

Four aircraft equipped with single flow engines ($F_o/D_o \geq 600$), the effect is given approximately by Fig. 12 (jet noise as a function of F_o/D_o), since for great specific thrusts the influence of F_o/D_o on take-off distance and on the angle of climb is small.

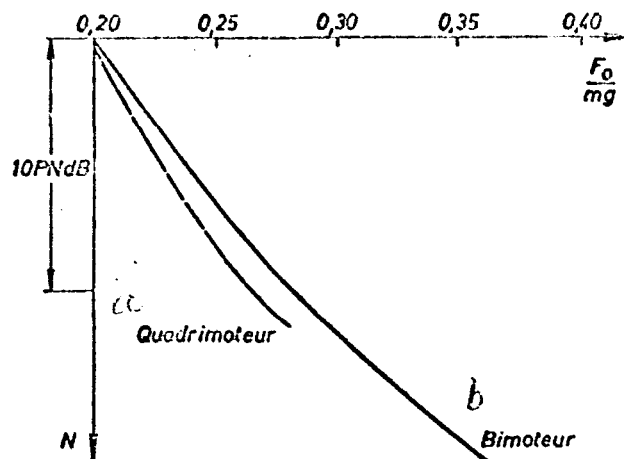


Fig. 18. Influence of engine power on take-off noise.

Key: a. Four-engined aircraft
b. Twin-engined aircraft

Special interest was shown in the four-engined aircraft with F_0/D_0 of less than 500, where a variation in F_0/D_0 should involve an increase in the power rating to maintain cruise thrust (it is assumed that cruise thrust varies as a function of F_0/D_0 following the curve in Fig. 19). Noise without reduction at a measurement point at 6,500 m for a 150-ton four-engined aircraft is given in tables II and III and in Fig. 20. The present four-engined aircraft have an F_0/D_0 in the neighborhood of 400 (JT3D-3B) and an F_0/mg of the order of 0.21; the value of 118.8 PNdB is a very good representation of the noise level

Figure 20 clearly shows that replacement of the current jet engines by very diluted jet engines will not provide a very substantial gain in the sound level unless substantial progress is made in the reduction of compressor noise. A decrease of the order of 15 PNdB can be expected if compressor noise is attenuated accordingly. Methods that have been studied for several years (elimination of the intake impeller, rotor-stator deviation, decrease

TABLE II. Jet noise, in PNdB
(Standard 150-ton four engined
aircraft)

F_o/mg	F_o/D_o		
	300	400	500
0.194			121.2
0.21		111.8	117.8
0.23	102.8	107.8	114.3
0.25	100.1	105.1	
0.273	97.8		

TABLE III. Compressor noise down-
stream, in PNdB (Standard 150-ton four-
engined aircraft)

F_o/mg	F_o/D_o		
	300	400	500
0.194			120.2
0.21		118.8	116.8
0.23	116.8	114.8	113.3
0.25	114.1	112.1	
0.273	111.8		

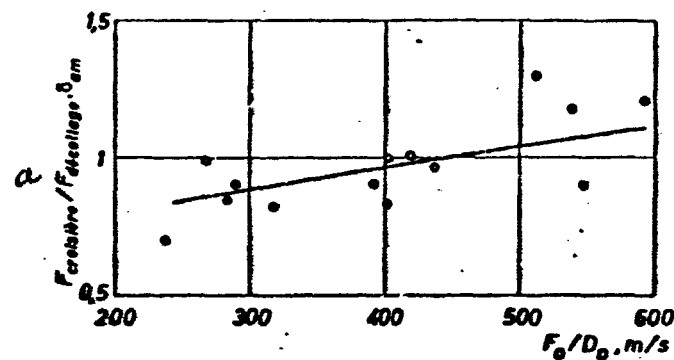
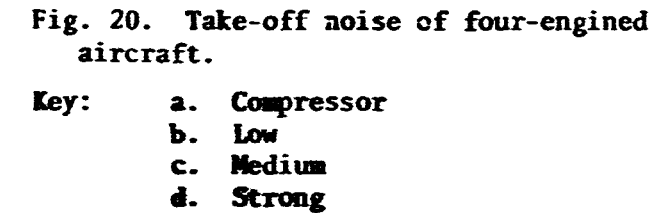


Fig. 19. Variation of cruise thrust as
a function of specific thrust F_o/D_o .

Key: a. $P_{cruise} / P_{take-off} \delta_{am}$

of peripheral velocity) will make it possible to achieve certain attenuations, but it will be necessary, however, to seek an attenuation supplement by means of acoustical treatments of the tubes downstream and upstream, or generally with compressor mufflers. Supplementary gains may be obtained by a boost in power (3 PNdB for a 10%, 5 PNdB for a 20% boost in power) and the reduction technique may then give 3 PNdB in the case of highly powered aircraft.



Key:

- a. Compressor**
- b. Low**
- c. Medium**
- d. Strong**

Key:

- a. Compressor**
- b. Low**
- c. Medium**
- d. Strong**

example, the time during which the sound level ranges between the maximum level

and the maximum level less 10 PNdB, and T_0 is a time constant equal to 15 secs. in this case.

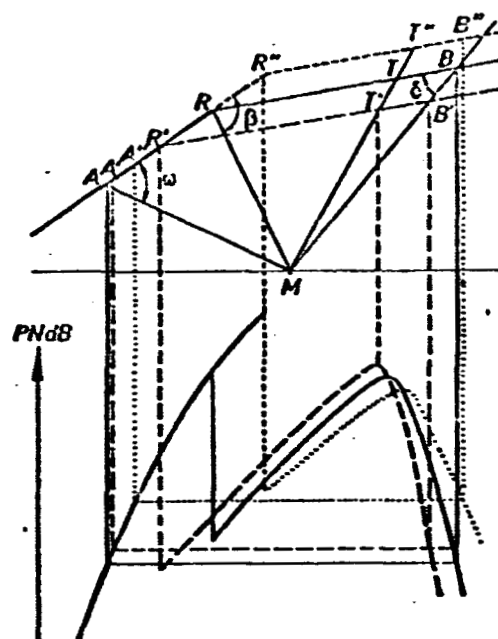


Fig. 21. Duration correction at optimum reduction.

Fig. 21 represents the sound level opposite the emission point. Since reduction is optimum, the two peaks derived respectively from the reduction point R and from the point T corresponding to the maximum angle of emission γ_{2m} , are equal. If one takes 10 PNdB below both peaks, the path ARB thus defined is the one corresponding to the desired Δt .

$$\text{Since } \alpha_1 - \alpha_2 \text{ is small opposite } \beta_r$$

$$ARB = h_1 \left[\cotg \omega + \cotg \delta + (\alpha_1 - \alpha_2) \right. \\ \left. (1 - \cotg \delta \cotg \beta_r) \right]$$

the angles ω and δ , defined in Fig. 21, are determined by the two relations

$$g_1(\omega) = 10 + g_1(\beta_r) \text{ and } g_2(\delta) = 10.$$

If reduction takes place too soon at R' , the first peak is substantially lowered, and it is the second peak, whose value increases slightly ($N'_{2m} = N_{2m} - K_2 \log h_2/h_1$), that gives the maximum sound level. In this case, T goes to T' , B goes to B' , and $\delta = \delta'$. If reduction takes place too late at R'' , the second peak decreases slightly, and it is the first peak, whose value is substantially increased, that yields the maximum sound level. In this case, T goes to T'' , B goes to B'' , but $\delta'' > \delta$. Studying the variation of the path ARB , one realizes that in both cases, whether reduction is premature or delayed, ΔARB is negative. Duration correction thus passes through a relative maximum when reduction is optimized.

Under these conditions, it is advisable to examine whether the optimized reduction point with PNdB remains the same with duration correction. Given the sharp increase in the sound level at the time of a delayed reduction, the displacement of the reduction point can only occur with a premature reduction, a case where it is a priori possible that the decrease in the duration correction will compensate for the increase in sound level.

As reduction is premature, the maximum level at the measurement point M is derived from the point T' corresponding to the angle of maximum emission. This level is $N_{2m} - K_2 \log h_2/h_1$ and the corresponding duration correction is $10 \log (A'R'B')/VT_0$. We therefore seek the maximum of the function

$$y = N_{2m} - K_2 \log h_2/h_1 + 10 \log (A'R'B') + \text{constant}$$

If there is a solution $\omega' > \omega$ cancelling the derivative of y with respect to β and compatible with $g_1(\omega) - g_1(\beta_p) = 10$, the optimum reduction in EPNdB occurs earlier than the one in PNdB. Not all possible cases can be examined here, but it should be pointed out, by way of example, that there is no solution for the Caravelle III: the optimum reduction in EPNdB agrees with that in PNdB.

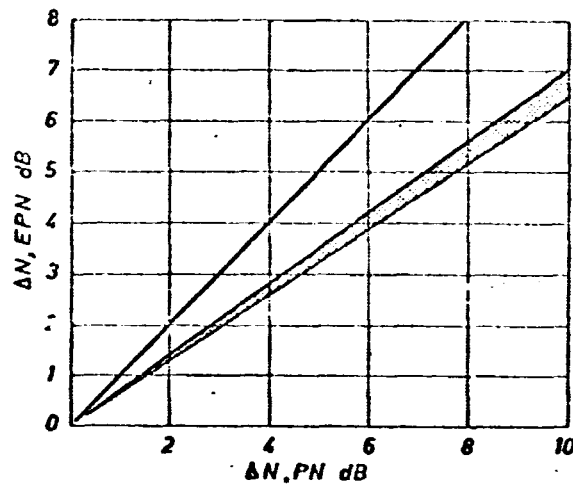


Fig. 22. Influence of duration correction on reduction gain.

Reduction gain in EPNdB is smaller than in PNdB. Actually, when the development of noise as a function of time presents two peaks, duration correction is greater than for a single peak. The remarkable fact is that the difference between duration corrections with and without reduction depend hardly at all on the sound field, but only on the reduction gain in PNdB. Figure 22 shows the results of the computation of ΔN in EPNdB as a function of ΔN in PNdB for the four sound fields in Fig. 17,a; all the curves are located inside the gray area. Loss due to duration correction is quite substantial since it represents one third of the gain in PNdB.

As power increases, h_1 increases, and the duration correction, which is approximately equal to $10 \log h_1(\cot \omega + \cot \delta)/VT_0$, increases as well. Thus, and in a substantial manner, the introduction of the duration correction penalizes (Fig. 23) aircraft with powerful engines. The influence of power is much smaller in EPNdB (Fig. 24); duration correction eliminates about one third of the gain provided by power in a twin jet and about one half in a four jet-engine aircraft. When the aircraft uses reduction, the duration

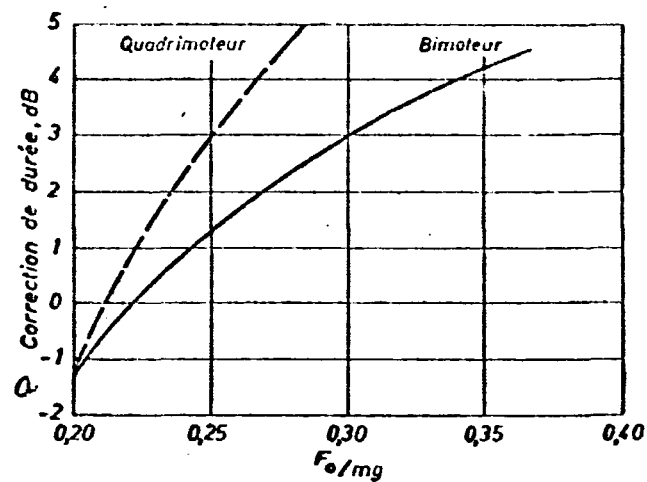


Fig. 23. Variation of duration correction as a function of power

Key: a. Duration correction

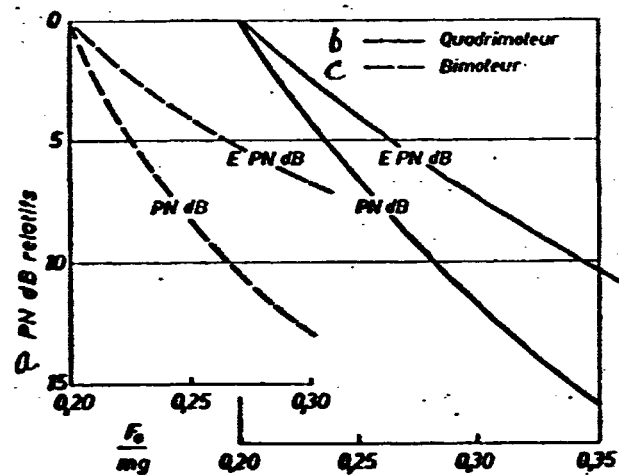


Fig. 24. Influence of power on take-off noise.

Key: a. Relative PNdB
b. Four-engined aircraft
c. Twin-engined aircraft

corrections are even more substantial (Table IV). Due to this fact, duration correction limits the validity of the reduction technique considerably (Table V).

TABLE IV. Duration corrections for a standard twin jet-engine aircraft

	Duration correction (dB)	
	With reduction	Without reduction
0.2	- 0.27	- 1.27
0.24	+ 3.12	+ 0.82
0.28	+ 5.06	+ 2.3
0.32	+ 6.5	+ 3.5
0.36	+ 7.4	+ 4.4

TABLE V. Reduction gain for a standard twin jet-engine aircraft

	Reduction gain	
	(PNdB)	(EPNdB)
0.2	3.4	2.4
0.24	7	4.7
0.28	9.4	6.7
0.32	10.6	7.6
0.36	11.5	8.5

Generally, the more an aircraft manages to improve its climbing performance, and thus to get away from the airport zone rapidly, the greater the duration correction to be applied to it, and this is a paradox. The function of duration correction should be to discriminate between aircraft sound fields, it should induce builders to make efforts to improve (go thoroughly into) the sound fields, and not to discourage them from boosting engine power, from improving the aerodynamic features of the aircraft, or from perfecting anti-noise take-off procedures.

It is not advisable to adopt the duration correction unless it responds perfectly to man's physiological reactions. It is quite evident that duration must be considered on the basis of noised-induced annoyance, but only on a serious basis. It would seem to be better to take into account only the time during which the sound level exceeds a threshold deemed to be annoying (90 PNdB, for example). Thus the unfortunate and paradoxical effects of duration correction would be eliminated, or at least attenuated.